THE FIRST LOCATION OF A NATIONAL, LONG-TERM FOREST SOIL PRODUCTIVITY STUDY: METHODS OF COMPACTION AND RESIDUE REMOVAL [1]

Allan E. Tiarks, Melinda S. Kimble, and Michael L. Elliott-Smith [2]

Abstract. To ensure that Forest Service management practices do not reduce long-term soil productivity , a network of coordinated, long-term experiments is being established across the United States. This national study plan calls for three levels of compaction (none, moderate, and severe) and three levels of organic matter removal (bole only, total tree, and total aboveground biomass). In this paper, the establishment of the first of these installations in central Louisiana is discussed. A loader was used to reach in and lift logs off the uneompacted plots instead of equipment entering the plots during harvest. Moderately compacted plots were rolled by a pneumatic-tired compactor loaded to 2.34 Mg/m, while a 4.22 Mg/m load was used for the severely compacted plots. After treatment, the bulk densities at the 0- to 10-cm depth were 1.47, 1.54, and 1.60 g/cm^3 for the none, moderate, and severe levels, respectively. The densities at the 10- to 20-cm depth were 1.61, 1.63, and 1.69 g/cm^3, while the treatments had no effect at the 20-30 cm depth. Of the 98 Mg/ha aboveground biomass on the plots, the bole-only removal left 23 percent of the biomass while the total tree harvest left 6 percent. Biomass contained about 155, 17, 63, 100, and 25 kg/ha of nitrogen, phosphorus, potassium, calcium, and magnesium, respectively. The concentration of nutrients was higher in the foliage and understory components of the stand, so proportionately more nutrients were removed as the harvest intensity increased.

Introduction

Harvesting forests may lower long-term productivity on Coastal Plain soils that are commonly fragile and easily degraded. In the South, much of the present pine forest was cropland at some point in the last century. A decline in annual production during the previous agricultural phase demonstrated the fragility of the soils. Reduced crop yields, caused by erosion, low fertility, soil compaction, and low water-holding capacity, led to abandonment and eventual reforestation of these fields. The effects of forest management on soil productivity are less apparent because harvests are made in cycles of decades, not years. The degree of productivity loss will be related to the cumulative amount of equipment entering a stand and biomass

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[2] Soil Scientists, Southern Forest Exp. Sta., Pineville, LA.

removed, so a reduction may occur in any silvicultural system regardless of the type of management. Since the effects of management practices on soil productivity may not be obvious to land managers, formal, long-term monitoring and research studies are needed to develop proper management practices.

Legislation

Recognizing the insidious nature of the loss of soil productivity in public forests, Congress passed the National Forest Management Act of 1976. This law charges the Secretary of Agriculture with ensuring research and monitoring the effects of each management system to protect the permanent productivity of the land (USDA Forest Service 1983). The ensuing Code of Federal Regulations for Forest Planning requires the Forest Service to monitor the effects of prescriptions, including "significant changes in land productivity" (U.S. Code of Federal Regulations 1985). Soil quality monitoring is seen as a three-stage process whose first two stages, implementation and effectiveness monitoring, depend on professional judgment (USDA Forest Service 1987). The final stage, validation monitoring, depends on research results of measurable soil variables that are linked to soil productivity (Powers 1990). Of the many soil variables that may be affected by forest management practices, soil porosity and organic matter content seem to be the most important (Powers et al., 1990).

Soil Variables

Soil porosity, at a given particle density, is proportional to the bulk density. Although total soil porosities are important, pine root growth, infiltration, internal drainage, and other factors affecting long-term productivity are more closely related to the pore distribution (Soane 1990). Soil compaction by heavy equipment used for logging and site preparation can severely reduce macropore space, especially in the surface horizon. The amount of organic residue left on the surface can also influence the porosity of the soil. Organic residues protect the soil surface from raindrop impact, provide food and cover for burrowing soil animals, and increase soil aggregation.

Other Factors

Intensive harvest and site preparation practices that remove more than the bole can also affect the long-term productivity of the site by influencing the amount of nutrients available to the next rotation. The concentration of nutrients in the woody stem is much lower than in the other tree parts. For instance, in a 35-year-old loblolly pine (*Pinus taeda* L.), stems contain 72 percent of the aboveground organic matter, but only 22 percent of aboveground nitrogen and 32 percent of the phosphorus (Switzer and Shelton 1984). The trees contain only 2 to 12 percent of the nutrients in the system (Switzer and Shelton 1984), with the remainder in the soil. However, in Coastal Plain soils, the trees may contain as much as one-third of the phosphorus on the site (Wells and Jorgensen 1979). Thus, the amount of forest residue removed from a site will affect long-term soil productivity because much of the nutrient requirement is cycled through the aboveground biomass (Switzer and Nelson 1972).

Soil Productivity Study

For these reasons, Powers et al. (1990) proposed that a national, long-term soil productivity study be initiated with treatments that manipulate soil porosities and organic residues spanning the range of environmental stresses possible under present or future management. This series of stress experiments will develop the fundamental relationships between site disturbances, growth processes, and long-term productivity. The results will permit implementation of monitoring standards related to productivity on a solid, scientific basis. Study sites are to be located in all major timber types in the country, including 13 sites of loblolly pine on the Coastal Plain (Powers et al., 1989).

In this paper, the first installation of the national study on a loblolly pine site and the protocols of imposing the treatments are described. Development of standard protocols is necessary to ensure that sites presently being installed in California, Idaho, Louisiana, Minnesota, and North Carolina, as well as future locations, can be compared. The results also test the range of stress applied. As in any study, the validity of the interpretations will be greatest if the treatment levels are at the minimum, maximum, and midpoint of the range.

Methods

Location

The installation was located in a loblolly pine stand selected on the basis of typical stand structure, past management, and common soil series. The plots are on the Longleaf Tract of the Palustris Experimental Forest in the northwest quarter of the southwest quarter of section 26, T1N R3W in Rapides Parish. The study site is on rolling terrain of Malbis and Beauregard soils. The plots are on uniform 3 to 7 percent slopes (Malbis soil) and are surrounded by Beauregard soils on the ridge tops and Caddo soils along the lower slopes. Site index for loblolly pine on Malbis is 90 at base age 50 (Kerr et al., 1980).

Description of Preharvest Stand

The harvested stand was established as a direct seeded study in 1953. Initial survival was 2,500 seedlings/ha, but drought and competition from slender bluestem reduced this number to 1,032 seedlings/ha at the end of the second growing season. During mid- to late rotation, the stand had been thinned as part of normal management. The stand is in a range management area that has been grazed at a moderate stocking over the last decade. Winter prescribed burns were done on a 3- to 5-year cycle with the last 1 year before harvest.

After the plots for the present study were located, the pines and understory were measured and sampled. The diameter at breast height (dbh) of all live pines (dbh > 7.5 cm) was measured. The height of every tenth tree was measured with a clinometer. The height of the trees ranged from 12.2 to 27.1 m and averaged 20.5 m (Table 1). Average dbh was 30.3 cm, and ranged from 8.6 to 52.8 cm. The average density of trees was 226/ha.

Table 1. Number of trees, heigbt, and dbh per plot before harvest.

Compaction level	Organic matter removal	Density	Height	Dbh
		(trees/ha)	(m)	(cm)
None	Bole only	192	21.9	32.2
	Total tree	246	20.1	29.8
	Total aboveground	173	20.4	31.3
Moderate	Bole only	272	20.1	29.2
	Total tree	199	20.2	29.5
	Total aboveground	232	20.2	30.5
Severe	Bole only	213	20.1	29.1
	Total tree	267	20.9	29.9
	Total aboveground	239	20.3	31.4
Mean		226	20.5	30.3

From this information, three sample trees were selected by stratified random sampling to represent a cross-section of each plot. The trees were felled and disks were taken every 2 m for stem and nutrient analyses. All bark from these disks was dried, ground, and mixed to get a composite sample for each tree. A 30-degree sector of the wood in each disk was treated in the same way so that the material in the samples was proportional to the total in the tree (Au&moody and Greweling 1979). Branch and foliage samples were also taken from these trees. Total biomass of the pines was calculated using equations for dry weights (Baldwin 1987).

Combined herbaceous, litter, and forest floor samples were collected using a randomly-placed, square frame (0.47 x 0.47 m). Ten samples per plot were clipped, bagged, dried, weighed, and saved for nutrient analyses. Attempts to separate the litter and forest floor from grasses and other herbaceous materials proved to be hopeless. Brush cover was estimated by the line intersection method (six lines per plot) with random samples taken for nutrient analysis. The mass per unit area of brush was estimated from the weight of the litter and herbaceous sample by assuming an equal weight per unit of ground cover. The litter, herbaceous, forest floor, and brush components were summed to obtain biomass and nutrient values for the understory component.

Soil Measurements

Before plots were established, four transects were made 100-m apart with simple descriptions recorded every 20 m along each transect. This information was used to locate plots on uniform soils. A hand-coring apparatus (Ruark 1985) was used to take bulk density samples from the 0 to 10 cm depth at random locations on each plot before harvest. The variability found from this sampling indicated that seven samples are required for the measured bulk density to be within a range of 0.05 g/cm^3 at 90 percent probability. Ten samples were collected after application of the compaction treatments at the 0 to 10, 10 to 20, and 20 to 30 cm depths.

Experimental Design

The national "generic" study plan (Powers et al. , 1989) calls for a core installation of nine treatments consisting of a factorial of the following three levels of organic matter removal and soil compaction. Organic matter removal consisted of: (1) boles only removed; (2) total tree removed; and (3) total aboveground biomass removed. Soil compaction was: (1) no compaction; (2) moderate compaction; and (3) severe compaction. Each plot is split into a subplot receiving no herbicide and a subplot from which all non-pine vegetation will be removed by herbicides. Normal management practices are being applied to a 10th plot. None of the treatments is replicated, but this location is along the productivity gradient specified in the national plan. The data from all locations will be combined and analyzed using regression models.

The plots receiving moderate or severe levels of compaction are 65 x 65 m. A lo-m-wide access strip for logging was placed in the middle of the uncompacted plots so they are 65 x 75 m in size. Within each vegetation control subplot, there is a 20 x 50 m measurement plot. There are 160 pines planted in each measurement plot at a 2.5 x 2.5 m spacing.

Logging of Plots

The plots that were to be compacted were logged with a grapple skidder; logs were removed from the uncompacted plots by lifting them with a loader. Trees were delimbed before they were removed from plots designated bole-only removal; on the other plots the trees were delimbed after removal from the plots. The small amount of nonmerchantable material was treated like the limbs for the plot. The logging was done in November and December 1989 when soil moisture levels were low.

Compaction of Plots

A pneumatic-tired roller was towed by a farm tractor or small crawler to compact the plots. The machine is a metal box mounted on a front axle of six wheels and a rear axle of seven wheels, for a total rolling width of 2.13 m. The rear axle is offset by one tire width so the machine covers 100 percent of the surface. Inflation pressure of the 7.50 by 15 tires was maintained at 310 kilopascal (kpa). Sandbags filled to a known weight were used to adjust the ballast. In studies where flexible tires pass over soils with moderate bearing capacity, both the soil and the tire characteristics determine ground pressure in a complex way (Hakansson et al., 1988). In a forest, the presence of roots, stumps, and large animal burrows adds to the complexity. Since ground pressures are indeterminable, the loads are expressed as mass per unit of summed tire widths with the units of megagrams per meter (Mg/m). Before compaction of the plots, the weight of ballast plus machine required to initiate compaction was determined by trial and error to be 3 Mg, or 1.4 Mg/m. The load for the severely-compacted plots was preset at 9 Mg (4.2 Mg/m), as heavier loads increase the depth of compaction but not the degree at the surface (Voorhees et al., 1978). The load for the intermediate level was set as the logarithmic average between these two points (2.3 Mg/m).

After the ballast was loaded, three passes were made over each area in one direction, followed by three passes in a perpendicular direction, for a total of six passes over all areas on the plots. The machine was towed over short stumps and around larger ones. On bole-only removal plots, the pine limbs were pulled aside, the area compacted, and the limbs replaced and evenly distributed.

Planting

Seed from 10 half-sib families from Forest Service seed orchards in Louisiana and Mississippi were used to grow containerized seedlings. The families were selected for their ability to perform well in existing progeny tests. The seed was stratified and planted in containers in the spring of 1989, with the families separated and identified. Planting of the plots commenced on February 14 and was finished by March 14, 1990. The families were randomly planted in each plot, but 16 trees from each family were planted in each measurement plot, and the genetic identity of each tree was recorded. The same containerized material was used to plant the border rows. Seedlings killed by Pales weevil and unknown causes were replaced on March 2.6, 27, and again on April 12 with seedlings from the same families.

Cultural Treatments

All seedlings on the plots were sprayed with Dursban™ 3E on March 26 and 27, 1990. The insecticide was effective in control of the Pales weevil, and no additional insect damage was noted the 1st year. On half of each plot, competing vegetation will be controlled so that treatment effects on maximum productivity can be measured. A broad spectrum of herbicides will be used to control all competing vegetation until pine canopy closure , or about age 5. For control in the 1st year, Oust™ was sprayed at the rate of 0.42 kg/ha on June 1, 1990.

Normal Management Plots

To evaluate the effects of present standard or normal management practices, a control plot was established after the logging operation on an area that appeared to have been logged in a manner typical for the region. This plot was planted at the same time and with the same seedlings as the other plots. Half of this plot will be managed using present practices. The other half will be treated the same, except that 50 kg/ha of phosphorus fertilizer will be applied at the beginning of the fourth growing season. The delayed application is based on research at the experimental forest showing that phosphorus fertilizer is most effective if applied after the pines shade the grass competition.

Weather Station

A recording weather station was located at this installation and will be located at all future installations for two reasons. First, because the plots are being installed at different geographical locations in different years, the weather stations will be used to account for differences in climate. Second, the data will be used in process modeling of the vegetation development. The station was placed in an open area at least 30 m from the nearest plot to minimize changes caused by the growing stand. Climatic parameters measured include air and soil temperatures, wind speed and direction, rainfall, humidity, total solar radiation, photosynthetically active radiation, and soil water tension. Readings are made every 5 minutes, but only the hourly averages are recorded. The data are maintained on computer disk for easy manipulation. Recording commenced on February 23, 1990.

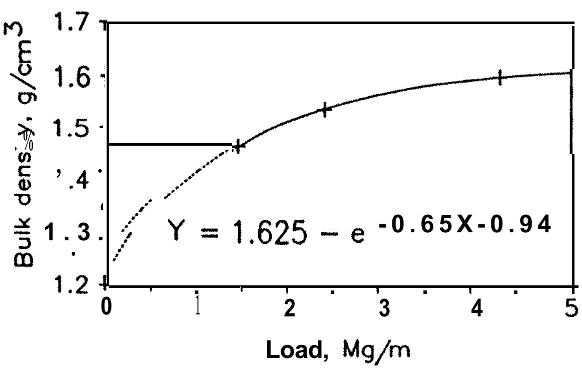

Figure 1. Effect of the different compactor loads on the bulk density in the 0 to 10 cm depth.

Results

Soil Bulk Densities

By trial and error in the field, an approximate relationship between applied load and bulk density was developed (Fig. 1) using an exponential curve (Larsen et al., 1980). The intersection of the curve with the Y axis indicates that the bulk density of this soil would be approximately 1.22 g/cm^3 in a normal state. However, past management, including grazing (Linnartz et al., 1966), compacted the surface to 1.47 g/cm^3, so loads up to 1.4 Mg/m were not sufficient to cause nonrecoverable compaction (Gill and Vanden Berg 1967). The load on the compactor was adjusted so the bulk density of the 0 to 10 cm layer of soil increased to 1.60 g/cm^3 for the severe level (Table 2, Fig. 1). The target density for the severe level was 1.61 g/cm^3, which is 80 percent of the difference between the growth-limiting density (Daddow and Warington 1983) and the original state. In the 0 to 10 cm layer, the bulk density of the moderately compacted plots was midway between the densities in the other two treatments.

The moderate level of compaction had little effect on the bulk density of the soil at the 10 to 20 cm depth, but the severe level increased the density from 1.61 to 1.69 g/cm^3. The compaction treatments had no effect on the bulk density of the soil at the 20 to 30 cm depth.

The effect of the compaction treatments on the distributions of bulk densities in the plots is shown in Figure 2. Even without additional compaction, densities ranged up to 1.65 g/cm^3. The compaction treatments eliminated any samples less than 1.40 g/cm^3 and increased the range up to 1.80 g/cm^3. Comparison of the distribution of densities on the different treatments indicates that the roller increased the bulk density without changing the standard error of the means (Table 2), showing that the entire plot was compacted uniformly and realistically.

Biomass And Nutrients Removed

The largest amount of biomass was in the boles of the pines harvested, with 78 percent of the dry weight in this component, which was removed by the bole-only removal treatment (Fig. 3). Another 17 percent of the total biomass was removed in the total tree removal, and only an additional 5 percent was removed in the total aboveground removal treatment. These numbers are the averages for the nine plots, not just the plots that received the targeted treatment. Individual plots were as much as 19 percent below to 21 percent above the means. The amount of nutrients in the stand ranged from 155 kg/ha for nitrogen to 17 kg/ha for phosphorus. As expected, the relative amount of nutrients removed was evenly distributed among the treatments even though most of the biomass was removed by the bole-only treatment (Fig. 3).

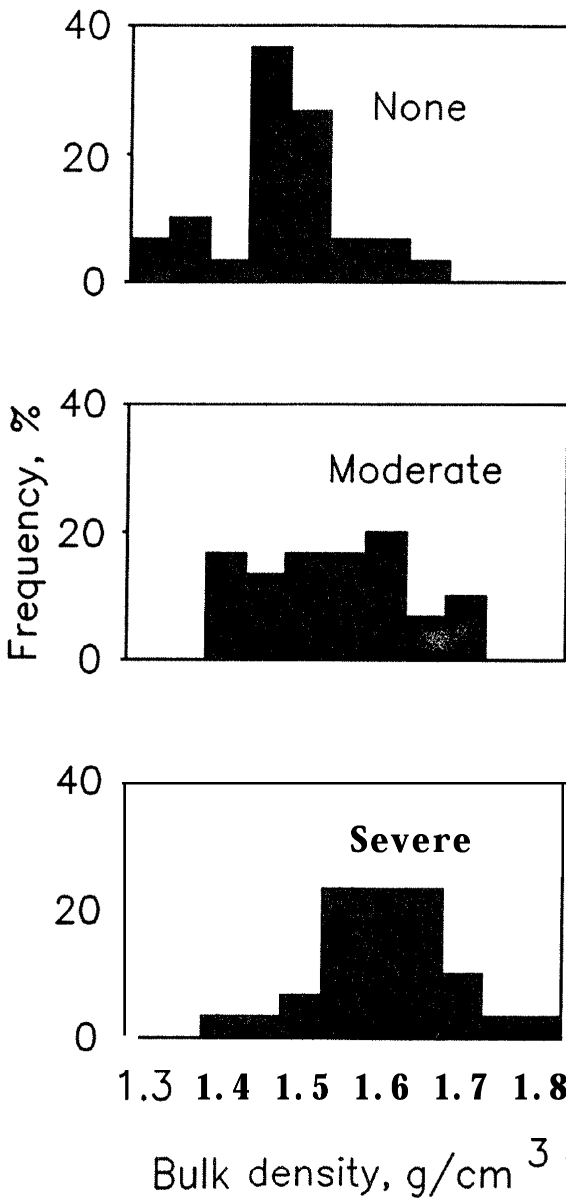

Figure 2. Distribution of bulk densities measured in the 0 to 10 cm depth after application of the compaction treatments.

Discussion And Conclusions

The initial bulk density of the surface soil was higher than expected, probably as a result of grazing (Linnartz et al., 1966). However, it was still possible to impose a range of bulk densities that should affect pine growth. As shown in Figure 2, the variability in bulk densities is about the same for the soil in the uncompacted and severely compacted plots, so the roller compacted the soil in an acceptably uniform and realistic manner. While more than three quarters of biomass on the site was removed by the bole-only treatment, about one-third of the nutrient capital was in the crowns and another quarter was in the understory (Fig. 3). Thus, in terms of quality of organic matter returned to the soil, the treatments imposed an acceptable range.

The plots will be maintained and measured throughout the 60-year rotation. During that time, the growth of the pines and other vegetation will be closely monitored for any changes in productivity. Soil and plant samples will be taken periodically to measure changes in nutrient availablity associated with the treatments. According to a regime to be developed based on basal area, the stand will be thinned later. Soil physical properties will be measured to follow the recovery of the soil after the compaction treatments. These measurements will include repeated bulk density samplings, penetrometer resistances, soil temperatures, and infiltration measurements.

It is hoped that other scientists will be able to use these plots to measure the effects of logging on the soil fauna and flora, especially as the network of plots is expanded across the country. The network of installations will be used to study the fundamental processes and relationships among tree growth and soil properties, organic residues, and climate. Models will be developed for use in the monitoring process so that the management of public forests will rest on a scientific foundation.

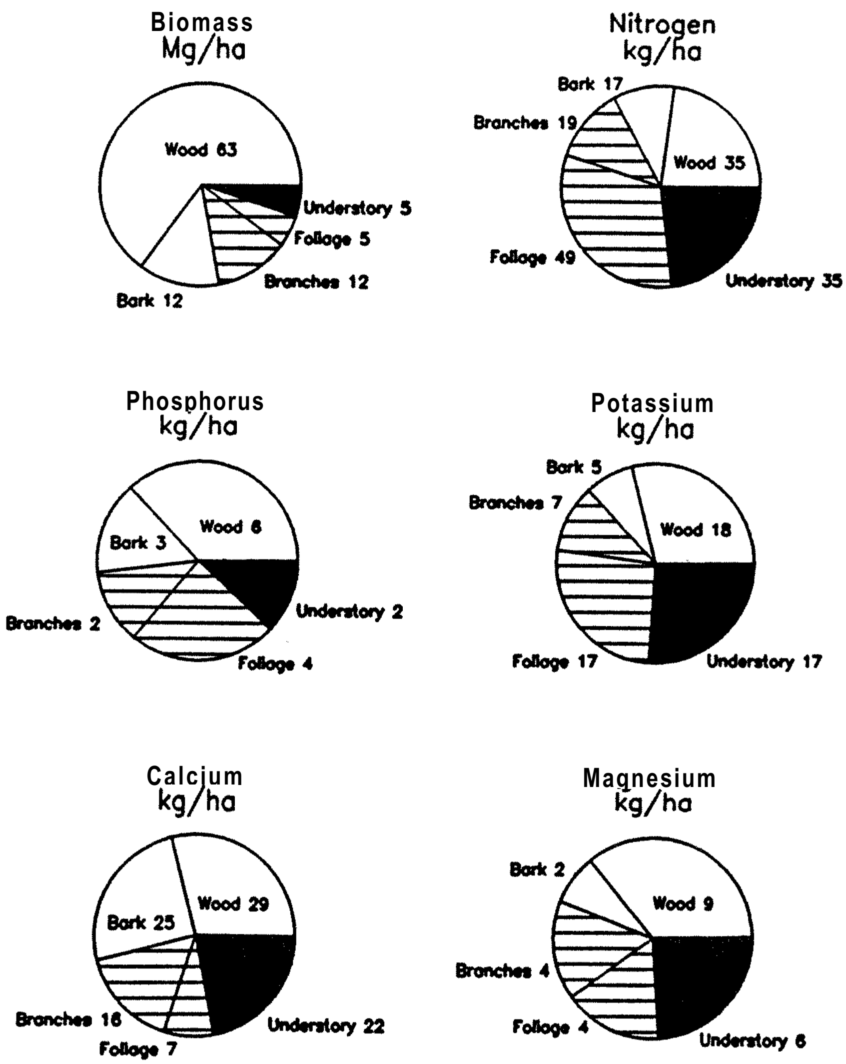

Figure 3. Relative amounts of biomass and nutrients of the different components of harvested stand. Open sectors are bole-only harvest; open plus hatched sectors represent the total tree harvest; and the complete pie is the aboveground material. Understory includes brush, grasses, herbs, litter, and forest floor. The numbers are the actual weights in each component.

Table 2. Average bulk densities of the soils after compaction at three depths over the three residue removal treatments and probability of treatment differences occurring by chance.

Sample depth	Compaction treatment None	Medium	Severe	Probability
(cm)	--------------(g/cm³)-I----------------			
0-10	1.47 (0.02)*	1.54 (0.01)	1.60 (0.02)	0.0001
10-20	1.61 (0.02)	1.63 (0.02)	1.69 (0.01)	0.0005
20-30	1.56 (0.01)	1.55 (0.02)	1.57 (0.01)	0.398

* Standard error of the means are shown in parentheses.

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